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HENRY DRAPER MEMORIAL.

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FIRST ANNUAL REPORT

OF THE

PHOTOGRAPHIC STUDY OF STELLAR SPECTRA

CONDUCTED AT THE

HARVARD COLLEGE OBSERVATORY,

EDWARD C. PICKERING, Director.

WITH PLATE.

CAMBRIDGE:
JOHN WILSON AND SON,
University Press.
1887.

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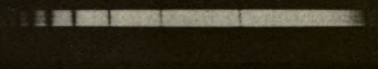

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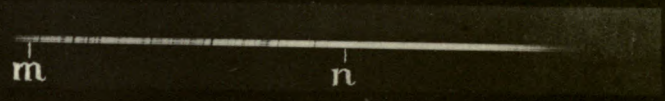

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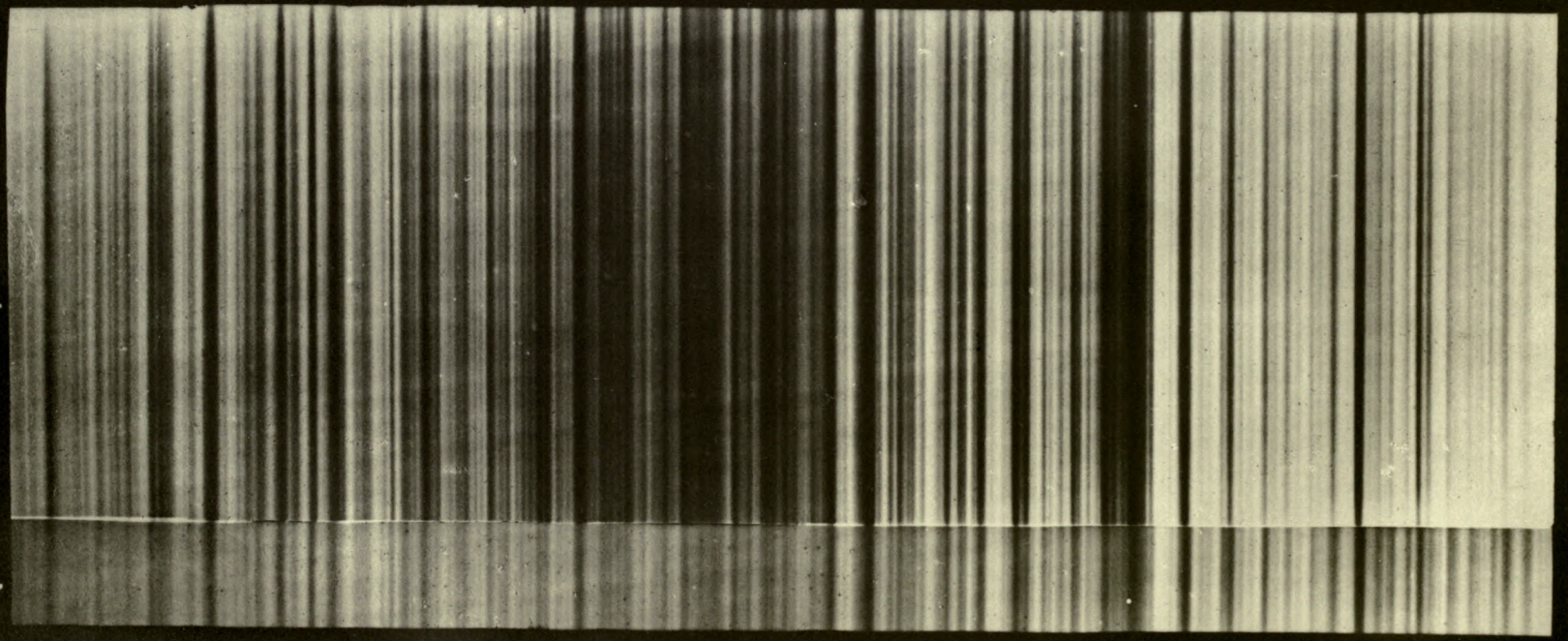

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FIRST ANNUAL REPORT.

Dr. Henry Draper, in 1872, was the first to photograph the lines of a stellar spectrum. His investigation, pursued for many years with great skill and ingenuity, was most unfortunately interrupted in 1882 by his death. The recent advances in dry-plate photography have vastly increased our powers of dealing with this subject. Early in 1886, accordingly, Mrs. Draper made a liberal provision for carrying on this investigation at the Harvard College Observatory, as a memorial to her husband. The results attained are described below, and show that an opportunity is open for a very important and extensive investigation in this branch of astronomical physics. Mrs. Draper has accordingly decided greatly to extend the original plan of work, and to have it conducted on a scale suited to its importance. The attempt will be made to include all portions of the subject, so that the final results shall form a complete discussion of the constitution and conditions of the stars, as revealed by their spectra, so far as present scientific methods permit. It is hoped that a greater advance will thus be made than if the subject was divided among several institutions, or than if a broader range of astronomical study was attempted. It is expected that a station to be established in the southern hemisphere will permit the work to be extended so that a similar method of study may be applied to stars in all parts of the sky. The investigations already undertaken, and described below more in detail, include a catalogue of the spectra of all stars north of —24° of the sixth magnitude and brighter, a more extensive catalogue of spectra of stars brighter than the eighth magnitude, and a detailed study of the spectra of the bright stars. This last will include a classification of the spectra, a determination of the wave lengths of the lines, a comparison with terrestrial spectra, and an application of the results to the measurement of the approach and recession of the stars. A special photographic investigation will also be undertaken of the spectra of the banded stars, and of the ends of the spectra of the bright stars. The instruments employed

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are an 8-inch Voigtländer photographic lens reground by Alvan Clark and Sons, and Dr. Draper's 11-inch photographic lens, for which Mrs. Draper has provided a new mounting and observatory. The 15-inch refractor belonging to the Harvard College Observatory has also been employed in various experiments with a slit spectroscope, and is again being used as described below. Mrs. Draper has decided to send to Cambridge a 28-inch reflector and its mounting, and a 15-inch mirror, which is one of the most perfect reflectors constructed by Dr. Draper, and with which his photograph of the Moon was taken. The first two instruments mentioned above have been kept at work during the first part of every clear night for several months. It is now intended that at least three telescopes shall be used during the whole night, until the work is interrupted by daylight.

The spectra have been produced by placing in front of the telescope a large prism, thus returning to the method originally employed by Fraunhofer in the first study of stellar spectra. Four 15° prisms have been constructed, the three largest having clear apertures of nearly eleven inches, and the fourth being somewhat smaller. The entire weight of these prisms exceeds a hundred pounds, and they fill a brass cubical box a foot on each side. The spectrum of a star formed by this apparatus is extremely narrow when the telescope is driven by clockwork in the usual way. A motion is accordingly given to the telescope slightly differing from that of the earth by means of a secondary clock controlling it electrically. The spectrum is thus spread into a band, having a width proportional to the time of exposure and to the rate of the controlling clock.

This band is generally not uniformly dense. It exhibits lines perpendicular to the refracting edge of the prism, such as are produced in the field of an ordinary spectroscope by particles of dust upon the slit. In the present case, these lines may be due to variations in the transparency of the air during the time of exposure, or to instrumental causes, such as irregular running of the driving clock, or slight changes in the motion of the telescope, resulting from the manner in which its polar axis is supported. These instrumental defects may be too small to be detected in ordinary micrometric or photographic observations, and still sufficient to affect the photographs just described.

A method of enlargement has been tried which gives very satisfactory results, and removes the lines above mentioned as defects in the negatives. A cylindrical lens is placed close to the enlarging lens, with its axis parallel to the length of the spectrum. In the apparatus actually employed, the length of the spectrum, and with it the dispersion, is increased five times, while the breadth is made in all cases about four inches. The advantage of this arrangement is, that it greatly

reduces the difficulty arising from the feeble light of the star. Until very lately, the spectra in the original negatives were made very narrow, since otherwise the intensity of the starlight would have been insufficient to produce the proper decomposition of the silver particles. The enlargement being made by daylight, the vast amount of energy then available is controlled by the original negative, the action of which may be compared to that of a telegraphic relay. The copies therefore represent many hundred times the original energy received from the stars. If care is not taken, the dust and irregularities of the film will give trouble, each foreign particle appearing as a fine spectral line.

Other methods of enlargement have been considered, and some of them tried, with the object of removing the irregularities of the original spectra without introducing new defects. For instance, the sensitive plate may be moved during the enlargement in the direction of the spectral lines; a slit parallel to the lines may be used as the source of light, and the original negative separated by a small interval from the plate used for the copy; or two cylindrical lenses may be used, with their axes perpendicular to each other. In some of these ways the lines due to dust might either be avoided or so much reduced in length as not to resemble the true lines of the spectrum.

The 15-inch refractor is now being used with a modification of the apparatus employed by Dr. Draper in his first experiments, — a slit spectroscope from which the slit has been removed. A concave lens has been substituted for the collimator and slit, and, besides other advantages, a great saving in length is secured by this change. It is proposed to apply this method to the 28-inch reflector, thus utilizing its great power of gathering light.

The progress attained is best shown by the accompanying Plate. Figure 1 is a direct copy of the spectra obtained in 1882. They were made by placing a 30° prism in front of a Voigtländer lens having an aperture of two inches and a focal length of seven inches. The exposures lasted for about five minutes, and no clockwork was used. The instrument was directed successively to α *Lyræ*, α *Aquilæ*, α *Bootis*, and β and γ *Ursæ Minoris*, all of whose spectra appear in the figure. Figure 2 represents the spectra of ζ *Ursæ Majoris*, and of the adjacent fifth-magnitude star. It was taken with the 8-inch Voigtländer lens, with an exposure of five minutes, and illustrates the size of spectra used in preparing the catalogue of spectra of the brighter stars. One or two hundred of these spectra are sometimes photographed upon a single plate. Figure 3 was obtained with the Draper 11-inch telescope, with two prisms. It represents the spectrum of α *Lyræ*, and was taken on November 5, 1886, with an exposure of 59 minutes. Figure 4 was taken

on January 21, 1887, in 50 minutes, with four prisms attached to the same instrument. It represents the spectrum of β *Geminorum*. All of these figures are made by direct printing from the original negatives. A positive was first made by laying the original plates in turn on a sensitive plate and exposing it to the light. A negative was formed from this in the same manner, which by the Albertype process was reproduced on paper. Figure 5 illustrates the method of enlargement described above. It represents the portions of Figure 4 contained between the points marked *m* and *n*. The entire spectrum would therefore have a length nearly double that here represented. A less perfect spectrum of the same star was obtained on January 12, 1887. A portion of its enlargement is given in Figure 6, adjacent to Figure 5. Nearly all the lines of Figure 5 are shown less clearly in Figure 6. Some of the remainder are due to the irregularities of the film described above, but they are probably too minute to be visible in the paper prints.

The results to be derived from the large number of photographs already obtained can only be stated after a long series of measurements and a careful reduction and discussion of them. An inspection of the plates, however, shows some points of interest. A photograph of α *Cygni*, taken November 26, 1886, shows that the H line is double, its two components having a difference in wave length of about one ten-millionth of a millimeter. A photograph of *o Ceti* shows that the lines G and *h* are bright, as are also four of the ultra violet lines characteristic of spectra of the first type. The H and K lines in this spectrum are dark, showing that they probably do not belong to that series of lines. The star near χ^1 *Orionis*, discovered by Gore in December, 1885, gives a similar spectrum, which affords additional evidence that it is a variable of the same class as *o Ceti*. Spectra of *Sirius* show a large number of faint lines besides the well-known broad lines.

The dispersion employed in any normal map of the spectrum may be expressed by its scale, that is, by the ratio of the wave length as represented to the actual wave length. It will be more convenient to divide these ratios by one million, to avoid the large numbers otherwise involved. If one millionth of a millimeter is taken as the unit of wave length, the length of this unit on the map in millimeters will give the same measure of the dispersion as that just described. When the map is not normal, the dispersion of course varies in different parts. It increases rapidly towards the violet end when the spectrum is formed by a prism. Accordingly, in this case the dispersion given will be that of the point whose wave length is 400. This point lies near the middle of the photographic spectrum when a prism is used, and is not far from the H line. The dispersion may accordingly be found with sufficient accuracy by measuring the interval between the H and K lines, and

dividing the result in millimeters by 3.4, since the difference in their wave lengths equals this quantity. The following examples serve to illustrate the dispersion expressed in this way: Angström, Cornu, 10; Draper, photograph of normal solar spectrum, 3.1 and 5.2; Rowland, 23, 33, and 46; Draper, stellar spectra, 0.16; Huggins, 0.1. Fig. 1, 0.06; Fig. 2, 0.10; Fig. 3, 0.63; Fig. 4, 1.3; Figs. 5 and 6, 6.5.

The most rapid plates are needed in this work, other considerations being generally of less importance. Accordingly the Allen and Rowell Extra Quick plates have been used until recently. It was found, however, that they were surpassed by the Seed Plates No. 21, which were accordingly substituted for them early in December. Recognizing the importance of supplying this demand for the most sensitive plates possible, the Seed Company have recently succeeded in making still more sensitive plates, which we are now using. The limit does not seem to be reached even yet. Plates could easily be handled if the sensitiveness were increased tenfold. A vast increase in the results may be anticipated with each improvement of the plates in this respect. Apparatus for testing plates, which is believed to be much more accurate than that ordinarily employed, is in course of preparation. It is expected that a very precise determination will be made of the rapidity of the plates employed. Makers of very rapid plates are invited to send specimens for trial.

The photographic work has been done by Mr. W. P. Gerrish, who has also rendered important assistance in other parts of the investigation. He has shown great skill in various experiments which have been tried, and in the use of various novel and delicate instruments. Many of the experimental difficulties could not have been overcome but for the untiring skill and perseverance of Mr. George B. Clark, of the firm of Alvan Clark and Sons, by whom all the large instruments have been constructed.

The progress of the various investigations which are to form a part of this work is given below: —

1. *Catalogue of Spectra of Bright Stars.* — This is a continuation of the work undertaken with the aid of an appropriation from the Bache Fund, and described in the Memoirs of the American Academy, Vol. XI. p. 210. The 8-inch telescope is used, each photograph covering a region 10° square. The exposures for equatorial stars last for five minutes, and the rate of the clock is such that the spectra have a width of about 0.1 cm. The length of the spectra is about 1.2 cm. for the brighter, and 0.6 cm. for the fainter stars. The dispersion on the scale proposed above is 0.1. The spectra of all stars of the sixth magnitude and brighter will generally be found

upon these plates, except in the case of red stars. Many fainter blue stars also appear. Three or four exposures are made upon a single plate. The entire sky north of —24° would be covered twice, according to this plan, with 180 plates and 690 exposures. It is found preferable in some cases to make only two exposures; and when the plate appears to be a poor one, the work is repeated. The number of plates is therefore increased. Last summer the plates appeared to be giving poor results. Dust on the prisms seemed to be the explanation of this difficulty. Many regions were reobserved on this account. The first cycle, covering the entire sky from zero to twenty-four hours of right ascension, has been completed. The work will be finished during the coming year by a second cycle of observations, which has already been begun. The first cycle contains 257 plates, all of which have been measured, and a large part of the reduction completed. 8,313 spectra have been measured on them, nearly all of which have been identified, and the places of a greater portion of the stars brought forward to the year 1900, and entered in catalogue form. In the second cycle, 64 plates have been taken, and about as many more will be required. 51 plates have been measured and identified, including 2,974 spectra. A study of the photographic brightness and distribution of the light in the spectra will also be made.

The results will be published in the form of a catalogue resembling the Photometric Catalogue given in Volume XIV. of the Annals of Harvard College Observatory. It will contain the approximate place of each star for 1900, its designation, the character of the spectrum as derived from each of the plates in which it was photographed, the references to these plates, and the photographic brightness of the star.

2. *Catalogue of Spectra of Faint Stars.* — This work resembles the preceding, but is much more extensive. The same instrument is used, but each region has an exposure of an hour, the rate of the clock being such that the width of the spectrum will be as before 0.1 cm. Many stars of the ninth magnitude will thus be included, and nearly all brighter than the eighth. In one case, over three hundred spectra are shown on a single plate. This work has been carried on only in the intervals when the telescope was not needed for other purposes. 99 plates have, however been obtained, and on these 4,442 spectra have been measured. It is proposed to complete the equatorial zones first, gradually extending the work northward. In all, 15,729 spectra of bright and faint stars have been measured.

3. *Detailed Study of the Spectra of the Brighter Stars.* — This work has been carried on with the 11-inch photographic telescope used by Dr. Draper in his later researches. A wooden observatory was constructed about 20 feet square. This was surmounted

by a dome having a clear diameter of 18 feet on the inside. The dome had a wooden frame, sheathed and covered with canvas. It rested on eight cast-iron wheels, and was easily moved by hand, the power being directly applied. Work was begun upon it in June, and the first observations were made with the telescope in October. Two prisms were formed by splitting a thick plate of glass diagonally. These gave such good results that two others were made in the same way, and the entire battery of four prisms is ordinarily used. The safety and convenience of handling the prisms is greatly increased by placing them in square brass boxes, each of which slides into place like a drawer. Any combination of the prisms may thus be employed. As is usual in such an investigation, a great variety of difficulties have been encountered, and the most important of them have now been overcome.

4. *Faint Stellar Spectra.* — The 28-inch reflector will be used for the study of the spectra of the faint stars, and also for the fainter portions near the ends of the spectra of the brighter stars. The form of spectroscope mentioned above, in which the collimator and slit are replaced by a concave lens, will be tried. The objects to be examined are, first, the stars known to be variable, with the expectation that some evidence may be afforded of the cause of the variation. The stars whose spectrum is known to be banded, to contain bright lines, or to be peculiar in other respects, will also be examined systematically. Experiments will also be tried with orthochromatic plates and the use of a colored absorbing medium, in order to photograph the red portions of the spectra of the bright stars. Quartz will also be tried to extend the images towards the ultra violet.

5. *Absorption Spectra.* — The ordinary form of comparison spectrum cannot be employed on account of the absence of a slit. The most promising method of determining the wave lengths of the stellar spectra is to interpose some absorbent medium. Experiments are in progress with hyponitric fumes and other substances. A tank containing one of these materials is interposed, and the spectra photographed through it. The stellar spectra will then be traversed by lines resulting from the absorption of the media thus interposed, and, after their wave lengths are once determined, they serve as a precise standard to which the stellar lines may be referred. The absorption lines of the terrestrial atmosphere would form the best standard for this purpose if those which are sufficiently fine can be photographed.

6. *Wave Lengths.* — The determination of the wave lengths of the lines in the stellar spectra will form an important part of the work which has not yet been begun. The approximate wave lengths can readily be found from a comparison with the solar spectrum, a sufficient number of solar lines being present in most stellar spectra. As a difference of one ten-millionth of a millimeter in wave length

exceeds half a millimeter in Figures 5 and 6 of the accompanying Plate, the readings may be made with considerable accuracy by a simple inspection. For greater precision special precautions are necessary on account of the deviation caused by the approach and recession of the stars. The deviation found by Dr. Huggins in the case of *Sirius* would correspond to a change in the position of the lines of Figures 5 and 6 of about half a millimeter. If, then, satisfactory results are obtained in the preceding investigation, the motion of the stars can probably be determined with a high degree of precision. The identification of the lines with those of terrestrial substances will of course form a part of the work, but the details will be considered subsequently.

From the above statement it will be seen that photographic apparatus has been furnished on a scale unequalled elsewhere. But what is more important, Mrs. Draper has not only provided the means for keeping these instruments actively employed, several of them during the whole of every clear night, but also of reducing the results by a considerable force of computers, and of publishing them in a suitable form. A field of work of great extent and promise is open, and there seems to be an opportunity to erect to the name of Dr. Henry Draper a memorial such as heretofore no astronomer has received. One cannot but hope that such an example may be imitated in other departments of astronomy, and that hereafter other names may be commemorated, not by a needless duplication of unsupported observatories, but by the more lasting monuments of useful work accomplished.

EDWARD C. PICKERING,
Director of Harvard College Observatory.

CAMBRIDGE, MASS., U. S. A.,
March 1, 1887.

HENRY DRAPER MEMORIAL.

SECOND ANNUAL REPORT

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SECOND ANNUAL REPORT.

The additional facilities provided by Mrs. Draper have permitted a considerable extension of this research during the past year. The 11-inch refractor belonging to Dr. Draper, and the 8-inch photographic telescope provided by the Bache Fund, have been kept at work throughout every clear night. The 28-inch and 15-inch reflectors constructed by Dr. Draper have been moved to Cambridge, and the first of these instruments is placed in a building surmounted by a dome constructed for the purpose. Experiments are now in progress with it, and it will probably soon be employed regularly. Four assistants take part in making the photographs, one of whom comes to the Observatory every clear night about midnight, and keeps the 8-inch and 11-inch telescopes in use until interrupted by the morning twilight. Five ladies have been employed in the measurements and reductions.

The various investigations now in progress are described in detail below. The first three of these, including the photographic work of the 8-inch and 11-inch telescopes, will be finished in about a year. It is accordingly proposed in the autumn of 1889 to send an expedition to the southern hemisphere, probably to Peru, and there complete the work to the south pole. As only about one quarter part of the sky is too far south to be conveniently observed at Cambridge, it is expected that the photographs needed to cover this portion of the sky could be obtained in two years. Each investigation could thus be extended to all parts of the sky upon the same system.

The present location of the various instruments is shown in the Frontispiece to this Report. It represents the rear of the Harvard College Observatory, and is taken from the top of a cottage to the northwest of the main building. Of the three domes in the foreground the right-hand one contains the 11-inch photographic telescope, and the central one the 28-inch reflector. The 15-inch reflector has been attached to the tube standing between the two domes. The

8-inch telescope is mounted in the shed between the central dome and the dome to the left, which contains a 13-inch and a 10-inch photographic telescope. The east wing of the main building is to the right, and is mainly devoted to the computing work described below. The cottage from which the picture is taken contains a large dark room, in which all the photographs are developed, an adjoining room for general experimenting, a room for clerical work, and a room which may be darkened and light thrown in by a mirror; this room is used for enlargements and other experimental work.

An important advance has been made by the recent improvements in the manufacture of dry plates. The M. A. Seed Company of St. Louis have endeavored to comply with our request for more sensitive plates, and have gradually increased their sensitiveness, so that they now furnish us with plates measuring 27 on their scale, while a year ago the most sensitive plates were only numbered 21. As a result, stars nearly a magnitude fainter can be photographed, and the number of objects which can be examined is nearly doubled. A careful study will shortly be made, by the help of the instruments described below, of the most sensitive plates obtainable. It is hoped that makers of very sensitive plates will send specimens to Cambridge for trial. The demand for increased sensitiveness is so great not only here, but at all other observatories where stellar photography is carried on, that a real improvement would be widely appreciated.

Various improvements have been made in the methods of detecting defects in the photographic processes. Each plate, when it is taken from its box, is exposed to a standard light for exactly one second. The portion of the flame of an oil lamp shining through a small circular aperture constitutes the standard light. The exposure is made for a second by means of a pendulum, which allows the light to shine on the plate for this interval through a small square aperture. When the plate is developed, a dark square appears near its edge, whose intensity measures the sensitiveness of the plate, and also serves to detect any defect in its development. Passing clouds, or a variation in the clearness of the sky, are detected by an instrument called the Pole-star recorder. It consists of a telescope with a focal length of about three feet, placed parallel to the earth's axis. An image of the Pole-star is formed by it, and allowed to fall upon a sensitive plate, describing an arc of a circle, which is interrupted whenever clouds pass. The plate is changed every day, and the instrument is closed automatically by an alarm clock every morning before the twilight begins. Much trouble is experienced from the deposition of moisture on the objectives of the photographic telescopes, on account of their exposure to a large portion of the sky. The failure of some of the

earlier plates may be due to this cause. Moisture is now carefully looked for, and, if detected, removed by gently heating the objectives. Another test of the quality of the plates consists in occasionally exposing a plate in the 8-inch telescope to the circumpolar sky, first with and then without the prism. The trails of the stars near the pole and the spectra of the brighter stars are thus photographed. A comparison of the intensity of these images tests the condition of the air, the instrument, and the plates.

The various investigations will now be described in order, as in the last Report.

1. *Catalogue of Spectra of Bright Stars.* — The spectra of all the brighter stars have been photographed with the 8-inch telescope, giving an exposure of at least five minutes to each. Each plate contains from two to four regions ten degrees square. The plates representing the region north of —25° were divided into three series, which may be distinguished as polar, zenith, and equatorial. Each region is contained on two plates, and the work has been repeated in two successive years, so that at least four photographs should be obtained of all the brighter stars. If a plate proved poor, it was repeated, so that the very bright stars will appear in several plates. The photographic portion of this work was finished last November. If no plates had been repeated, 36 polar, 72 zenith, and 72 equatorial plates would have been required each year, or 360 in all. The actual numbers of plates taken and measured were 46, 120, and 93, total 259, the first year; and 61, 209, and 104, total 374, the second year; or 633 in all. In the later work the number of zenith plates was doubled, to avoid the confusion arising when several exposures were made on a single plate. The numbers of spectra measured on these plates were 2,381, 3,314, and 2,618, total 8,313, the first year; and 7,199, 8,217, and 4,074, total 19,490, the second year. Two plates covering the immediate vicinity of the north pole contain 150 spectra. The whole number of spectra is therefore 27,953. The measurement and identification of this large number of spectra has occupied the greater portion of the time of the corps of computers. Each plate to be measured was placed on a stand, and the light of the sky was reflected through it by means of a mirror. The approximate co-ordinates of each spectrum in turn were then read off, and a careful description of the spectrum was given. Besides the usual division into types, each additional line visible was recorded both as regards its position and intensity. The photographic intensity of the brighest portion of each spectrum was also measured by means of a photographic plate, dark at one end and light at the other, like a wedge of shade glass.

When the spectra show sudden changes in brightness, additional measurements are made. This portion of the work is complete only for the polar plates and about 62 of the other plates, including 12,574 spectra. The identification of the spectra is effected either by computation from its co-ordinates, or by laying the plate upon the maps of the Durchmusterung, the scale being the same for both. All the plates have, however, been checked by the latter method. The names of the stars are then taken from the Harvard Photometry, Uranometria Argentina, or Durchmusterung, according to their brightness and declination. Their places are next brought forward to 1900, the epoch of the final catalogue. As the intensity of the photograph of a given spectrum will vary greatly with the sensitiveness of the plate, the clearness of the air, and the rate of the driving clock, all must be reduced to the same system. The scale of the Harvard Photometry is adopted for this purpose. The most prevalent spectra are those of the first type, in which the K line is too faint to be visible. After applying a correction for the declination of the stars, the brightness of all such spectra on each plate is compared with the photometric magnitudes. A correction is thus derived for each plate, which is applied to all the spectra upon it. The effect of color, so far as it varies with the type of spectrum, is thus eliminated. It is possible that, owing to variations in temperature, or other causes, some stars may be redder or bluer than others having the same type of spectrum.

2. *Catalogue of Spectra of Faint Stars.* — Until the photographs required for the research mentioned above were completed, the time of the 8-inch telescope was mainly devoted to them. Since then it has been used principally in photographing the fainter stars. An exposure of one hour is given to each portion of the sky, a region ten degrees square being included upon each plate. Stars as far south as —25° can be advantageously photographed at Cambridge, and the plan proposed covers this region. The plates overlap, so that the region north of —20° will appear on at least two plates. The southern stars are only photographed when the sky is unusually clear. Each plate is examined, and, if unsatisfactory, the work is repeated. If all were good, 650 plates would be required. Thus far, 606 plates have been taken, covering 339 of the desired regions. As the time of the computers has been mainly devoted to the first investigation mentioned above, the greater portion of these plates have not been measured or reduced. The total number measured is 105 plates, containing 6,931 spectra, of which 94 plates and 6,293 spectra have been reduced. The form of reduction and publication will be similar to the catalogue of bright stars, except that it will be convenient to retain the Durchmusterung numbers and places, arranging the stars in the order of the zones in that catalogue.

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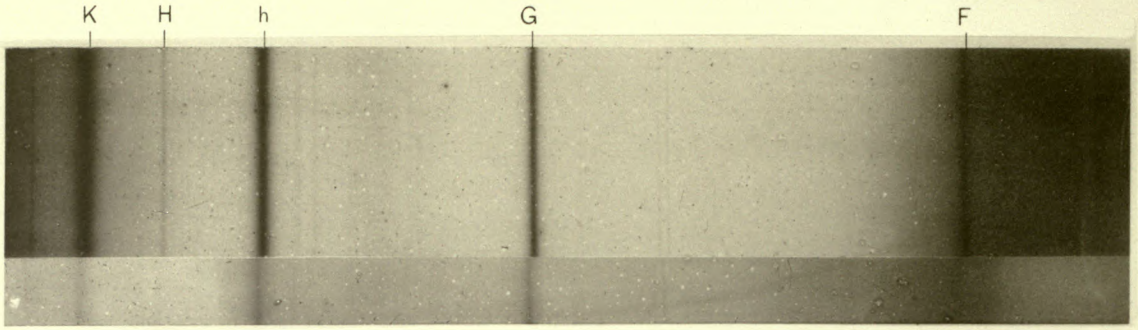

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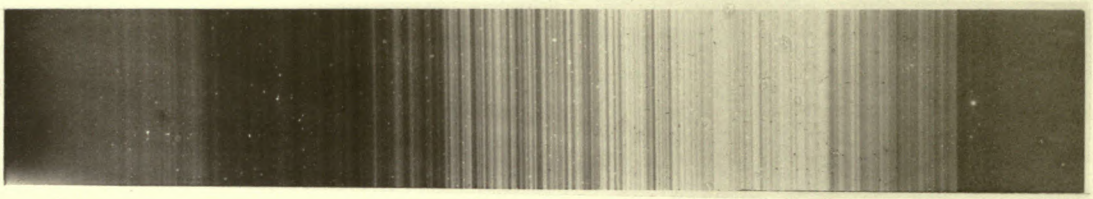

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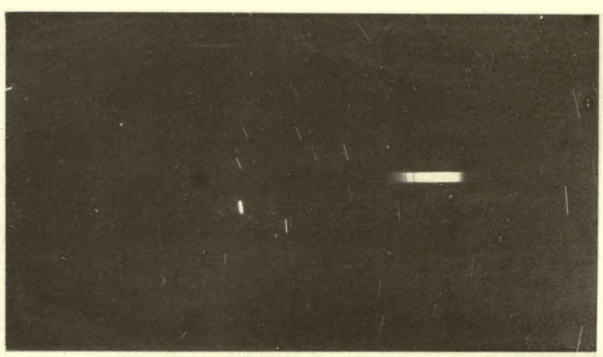

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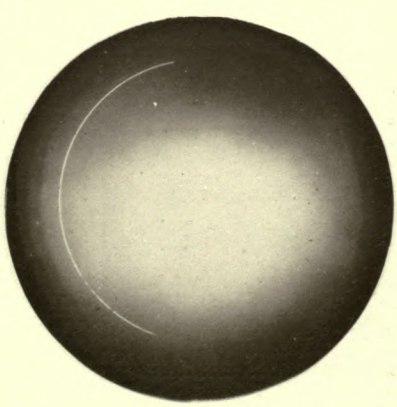

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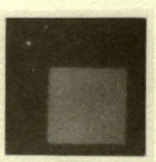

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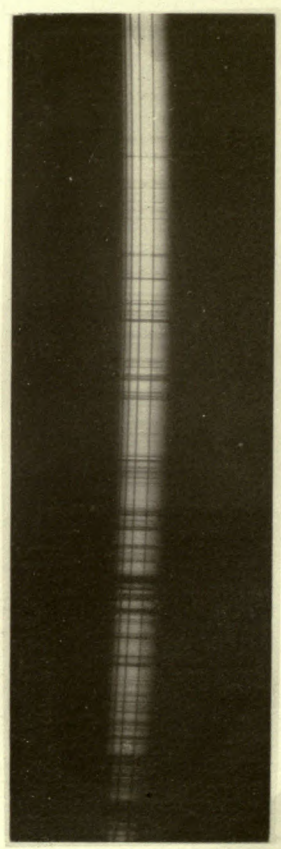

6

PLATE II.

It is hoped that the photographs for this investigation will be nearly all taken by the autumn of 1888, and the remainder during the following year. To provide for a possible increase in sensitiveness of the plates, precedence is given to those completely covering the sky once, the alternate plates, covering the sky the second time, being taken later. The actual improvement in the plates shows itself by an increase in the number of spectra in this second series of plates. In some cases over three hundred stellar spectra appear on a single plate.

3. *Detailed Study of the Spectra of the Brighter Stars.* — These spectra are obtained by placing four prisms, having an angle of about fifteen degrees and each nearly a foot square, over the object glass of the 11-inch telescope, as described in the last report. The increased sensitiveness of the plates has greatly increased the number of stars bright enough to produce a satisfactory image in this way. The white stars of the first type give good images when no brighter than the fourth magnitude. These spectra are about four inches in length. An improvement has been made in the method of enlargement with a cylindrical lens described in the last Report. When such a lens was used with an enlarging lens having a small aperture, the width of the spectrum was greatly reduced; with a large aperture, the best definition could not be attained. A slit perpendicular to the axis of the cylindrical lens is accordingly placed over it. This reduces the aperture in one direction so that the definition of the lines is good, without affecting the width of the spectrum. Slow plates are also used in the enlargements to increase the contrast. Much more brilliant spectra are thus obtained.

4. *Faint Stellar Spectra.* — As stated above, the 28-inch reflector constructed by Dr. Draper is now ready for use. The difficulties commonly encountered in the use of a large reflector have been met, and it is hoped successfully overcome. A spectroscope has been devised for this instrument which will give a dispersion about equal to that employed in the first and second of the researches described above. As the area of the aperture of this telescope is about eleven times that of the 8-inch telescope, it is hoped that much fainter stars can be photographed with it. A study will be made of the spectra of the variable stars of long period, of the banded stars, and of other objects having peculiar spectra.

But little progress has been made with the other investigations proposed, including the reduction to wave-lengths, and the study of the approach and recession of the stars. It seemed best to concentrate our work on the researches described above, undertaking the other investigations as soon as time permitted.

The investigations described above are illustrated by Plate II. A special study was made of the spectrum of the variable star β *Persei*. A variation in this

spectrum would have an important bearing on the theory that the diminution in light is due to an interposed dark satellite. Spectra of this star at minimum were first obtained with one prism. With the increased sensitiveness of the plates, more prisms were tried, until finally good spectra were obtained with all four prisms even when the star was at its minimum. At first it was thought that a variation was detected in the spectrum, but this change was not confirmed under more favorable circumstances. The upper part of Figure 1 shows the spectrum of this star on February 6, 1888, when at its full brightness; the lower part shows the spectrum on February 9, 1888, when the star was at its minimum. A careful inspection of the original negatives failed to show any differences in the spectra. Twenty lines are visible at minimum, all of which are seen at maximum. The difference in brightness of the ends of the spectrum is a photographic effect, not shown in the original negative. The spectrum of *α Orionis* is shown in Figure 2. Before the recent increase in the sensitiveness of the photographic plates, satisfactory photographs could not be obtained of the spectrum of this star, on account of its red color.

The method of testing plates by exposing them to the polar sky, as described above, is illustrated in Figure 3. The spectrum is that of the Pole-star. Although no clockwork is used, DM. +88°4, magnitude 6.5, leaves a distinct spectrum by trailing on the most sensitive plates. The short lines are the trails when no prism is used. Figure 4 represents the record of cloudiness on December 28, 1887, by the trail of the Pole-star. The breaks in the circular trail indicate the passage of clouds. From it we see that for about five minutes after $7^h\ 45^m$, when the record begins, the light was slightly dimmed by clouds. It was then clear until $9^h\ 0^m$; cloudy until $9^h\ 10^m$; clear until $9^h\ 40^m$; cloudy at times until $11^h\ 0^m$; clear until $17^h\ 35^m$, when the apparatus was closed automatically by the alarm clock. The square formed on this plate by the standard light is shown in Figure 5.

A means of studying the steadiness of the air and the twinkling of the stars is shown in Figure 6. The 8-inch telescope was directed to *α Lyræ* on October 17, 1887, and the spectrum of this star was allowed to trail across the plate, the telescope being at rest. The lines *G*, *b*, and *H* appear as nearly vertical lines. If the air was perfectly steady, a uniform band would be obtained. The irregularities of the air, which appeared perfectly clear to the eye, are shown in the upper part of the band. They increase in the lower part, when the star was obscured by passing clouds.

HENRY DRAPER MEMORIAL.

THIRD ANNUAL REPORT

OF THE

PHOTOGRAPHIC STUDY OF STELLAR SPECTRA

CONDUCTED AT THE

HARVARD COLLEGE OBSERVATORY,

EDWARD C. PICKERING, Director.

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THIRD ANNUAL REPORT.

The researches which constitute the Henry Draper Memorial have consisted for the last three years in the photographic study of the spectra of the stars. While this subject will continue to be the principal one under investigation, Mrs. Draper has decided to extend the field of work undertaken, so as to include the study of the other physical properties of the stars by photography. As will be seen from the detailed statement below, the first research undertaken is now rapidly approaching completion, the plans for the study of the southern stars have been matured, and this study will soon be begun; the detailed study of the spectra of the brighter stars is making progress, and a large piece of photometric work will soon be undertaken with a new telescope. The progress made in each investigation will now be described, as in previous reports.

1. *Catalogue of Spectra of Bright Stars.* — The Bache telescope, which has an 8-inch photographic doublet as an objective, is used for this work. The photographs cover the entire sky north of −25°, with exposures of about five or ten minutes. About 28,000 spectra of 10,800 stars have been examined, including nearly all stars visible in Cambridge of the seventh magnitude or brighter. The catalogue is now nearly ready for the printer, the final copy having been prepared as far as 14^h in right ascension.

Nearly the entire time of three or four computers has been devoted during the past year to this work. The intensity of about 15,000 of the spectra has been measured, completing this part of the research. Much time has been spent in checking and verifying the results. All the positions have been checked and brought forward to 1900 two or more times independently. All discordant measures have been re-examined, and a search has been made for possible error when bright stars are omitted or very faint ones inserted. Seven thousand two hundred notes have been made on the various stars in the catalogue. Each note has an appro-

priate number which permits it to be entered in its proper place. Most of these notes relate to additional lines contained in these spectra besides those by which the type is determined. The position and intensity of these lines is estimated. A portion of them have been reduced to wave-lengths. The printing of the catalogue might have been already begun, but for the difficulty of deciding how the different types of spectra should be distinguished. The classification used for visual observations fails to indicate many differences obvious in the photographs. On the other hand, the photographic portions of spectra of Types II. and III. are nearly identical. The photographs also show many stars whose spectra are intermediate between those of the typical stars which have determined the usual classification. A system has, however, been adopted which permits all differences detected in the photographs to be described in the printed volume.

Thirteen spectra were found on these plates which could not be identified with stars. Three of these proved to be due to Mars, one to Vesta, three to Jupiter, four to Saturn, and two to Uranus. Accordingly all the exterior planets bright enough to be detected in this way appear on these plates.

The measures of the intensity of the spectra form a very important portion of this work. Since the same part of the spectrum is measured in each case, the true relative energy is determined. That is, the same result is obtained as if the measures of rays of the same wave-length were made by any other method, as photometrically by the eye, by the thermopile, or by the bolometer. The color of the star will be indicated by the extent of the spectrum, which is also noted. For the first time, therefore, we shall have a photometric catalogue in which the error due to the color of the star is eliminated. A preliminary determination of the accordance of the results derived from different photographs of the same star shows that the average value of the residuals will be about 0.16, which is the same as the corresponding quantity for the Harvard Photometry. The number of stars is more than twice that contained in the latter Catalogue.

2. *Catalogue of Spectra of Faint Stars.* — In November, 1888, the photographs required to cover the sky north of the equator were nearly finished. It was expected that in two months the observations would be completed. The telescope, which was the same as that used in the previous research, was, however, wanted for photographing the Solar Eclipse of January 1, 1889. It was accordingly sent to Willows, California, where it was mounted, and the greater portion of the remaining photographs were taken there. It was then sent to Peru, as will be described below. The few remaining photographs, including the repetition of those found on further examination to be unsatisfactory, will be taken in Peru.

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3. *Detailed Study of the Spectra of the Brighter Stars.* — The 11-inch refractor with one, two, or four large prisms over its objective has been employed in this work throughout nearly every clear night, until stopped by the morning twilight; 686 photographs have been taken, most of them with an exposure of two hours. With our present photographic plates about 570 stars north of −30° are bright enough to be photographed with one prism, 170 of them with two prisms, and 87 of them with four prisms. To obtain the best possible result some of the photographs must be repeated many times. The difficulty is increased by the invariably hazy appearance of the lines in some spectra, like that of *α Aquilæ*, which was at first attributed to poor definition of the photograph. It is expected that the work will be completed during the next year by original or repeated photographs of 228 stars with one prism, of 64 with two, and of 12 with four. In general, stars as bright as the fourth magnitude can be satisfactorily photographed with one prism, the spectra obtained being about an inch long. Fainter stars, if of a bluish color, give sufficiently distinct images, in some cases good results being obtained with stars of the seventh magnitude. For example, fourteen stars in the Pleiades are well photographed with this apparatus. With four prisms much longer spectra are obtained and many more lines are visible. But certain differences in the character of the spectra are better shown with the smaller dispersion. Numerous photographs have been taken of the variable stars *o Ceti* and *β Lyræ*. The changes in the spectrum of the latter star seem to be undoubted, those of *o Ceti*, if any, to be slight. Various peculiarities in the spectra of individual stars have been detected. One photograph of *ζ Ursæ Majoris* shows the K line distinctly double, and others show it single. Many photographs will be required to determine the law of its variation, if this is due to changes in the star itself. Bright lines were detected in the spectrum of *φ Persei*, putting it in a class in which only two or three other stars are known to fall. In the double star *β Cygni* the two components have spectra of different types, an important consideration in the theories regarding their formation. The brighter component is of the second type, the fainter of the first.

Ordinary photographic plates are not sensitive to rays of much greater wave-length than the F line, or 486. By staining the plates with various coal-tar products the range of sensitiveness may be greatly extended. With erythrosin the spectrum extends to the wave-length 590. The sodium line D is distinctly seen to be double in the photographs of *α Bootis* and *α Aurigæ*. Various experiments were also made with cyanin, but the plates were not sufficiently sensitive to give good results. The entire length of the spectrum with four prisms, including the portion obtained by erythrosin, is about six inches and a half.

A beginning has been made of the measures of the positions of the lines in the spectrum. A scale of fortieths of an inch has been ruled on glass, and the positions of the lines read off with the aid of a magnifying-glass. Twelve of the photographs of *α Canis Majoris* have been studied in this way. The spectrum of this star is traversed by the hydrogen lines, which are strong, and by other lines which are so faint that they are only visible when the dispersion is large and the definition good. The catalogue thus formed contains about 320 lines. The average deviation of the measures of the same line on different plates is about 0.05 of a millionth of a millimetre, or 0.05 cm. on the scale of Angström's map. If the line occurs in the solar spectrum these measures will generally identify it. In other cases the exact position must be determined by a dividing engine. If a line can be distinctly seen, its wave-length can probably be thus determined with as great accuracy as that of the position of the solar lines on the map of Angström. In the spectrum of *α Bootis* 140 lines are visible between the D and F lines.

The classification of this large number of spectra is a matter of no little difficulty. Slight differences exist in many stars, and certain stars appear to hold an intermediate position, so as to render a rigorous division into classes impossible. On the other hand, many stars appear to have identical spectra. The first step will be to arrange the stars in groups, and then compare the best defined spectra of different groups. A minute discussion and the measurement of wave-lengths will be necessary only in the investigation of a comparatively small number of spectra.

4. *Faint Stellar Spectra.* — The 28-inch reflecting telescope constructed by Dr. Draper was assigned to this work. During the first six months of the year a careful study was made of this problem, and the difficulties encountered bore evidence of the skill of Dr. Draper in obtaining good results with this telescope. The best method of using this instrument seemed to be a modification of the form first tried by Dr. Draper, — a slit spectroscope from which the slit had been removed. The rays from the mirror were rendered parallel by a concave lens which replaced the objective of the collimator. As this lens had the same focal distance as the objective of the observing telescope, it was not necessary that either should be achromatic. After long trials with this and other forms of apparatus, a spectrum was at length obtained showing good definition. As the results were not better than those described above, and the instrument, from its size, was slow in operation, the experiments have not been carried further.

5. *Catalogue of Spectra of Bright Southern Stars.* — The 8-inch Bache telescope remained in California until February 2, 1889, and was then sent to Peru to continue research No. 1 on the southern stars. The sky from −25° to the south pole will

be covered, and the resulting photographs sent to Cambridge and reduced, as in the case of the northern stars. The advantages of discussing all stars from the north to the south pole according to one system are very great, and are here secured for the first time in so extensive an investigation. If no unforeseen difficulty arises, the photographs will all be completed during the next two years.

6. *Catalogue of Spectra of Faint Southern Stars.* — Research No. 2 will also be extended to the south pole simultaneously with the observations required for No. 5. It is expected that these photographs also will be completed in two years.

The Bache telescope described above has proved an extremely convenient instrument for various purposes. Besides the spectroscopic researches already mentioned, several other investigations have been undertaken with it, some of which will be found in the Memoirs of the American Academy, Vol. XI., p. 179, and the Harvard Observatory Annals, Vol. XVIII., Nos. IV., VI., and VII. Owing to its short focal length it possesses many advantages over photographic telescopes of the usual form. With exposures of an hour and a half more stars were photographed in the Pleiades than are given in the engraving accompanying the Annual Report of the Paris Observatory for 1886, although that work was based on photographs taken by the MM. Henry with exposures of three hours and a telescope having an aperture of 13 inches. Nearly twice as many stars were photographed in this region as were visible with the 15-inch telescope of the Harvard College Observatory. The short focus of the telescope also gives it especial advantages for photographing nebulæ. Twelve new nebulæ were thus discovered in a region where but eighteen were known before. Various other investigations, such as a determination of the law of atmospheric absorption, have been undertaken with the aid of this telescope. It has been so persistently used in spectroscopic work that the other researches have been neglected, especially those in which very long exposures were required. Its removal to Peru now cuts it off for some time from such use on the northern stars. Accordingly, Mrs. Draper has procured a similar lens, which is now in the hands of the firm of Alvan Clark & Sons for retouching and mounting. Several important researches will be undertaken with this instrument. Photography is now used in so many departments of astronomy that a general investigation of the photographic brightness of the stars seems desirable. A plan has been proposed by which a single plate will contain photographs of a number of regions one degree square, but in different portions of the sky. Thus a series of standard faint stars will be photographed, which can all be measured, and reduced to the same scale. One or more photographs of the vicinity of the north pole will be taken on each plate, and thus serve

to correct the results obtained on different plates. It is proposed in this way to secure a series of standards of stellar magnitude at intervals of about five degrees. A third lens of similar form, having an aperture of four inches, will be attached to the telescope, with which photographs on a smaller scale, but five degrees square, will be taken simultaneously. These photographs will cover the entire sky, and it is proposed to measure the photographic brightness of all stars of the seventh magnitude, or brighter, which are represented on them. This investigation will have a special value in connection with the photometric measures of the spectra described above. It is hoped also to photograph the entire northern sky by means of the 8-inch telescope, with exposures of an hour. Each plate covers a region nearly ten degrees square, of which the images in the central five degrees square are satisfactorily in focus. One of the regions containing standard stars will appear in the centre of each plate. By such a series of plates the photographic brightness of any stars brighter than the fifteenth magnitude can be determined on a uniform scale. The faintest stars photographed will be nearly a magnitude fainter than the limit proposed by the Astrophotographic Congress, so that all plates included in that work can be reduced to a uniform system. The advantages of such plates for studies of the distribution of the stars and other similar investigations are obvicus.

From the above description it appears that the field of work of the Henry Draper Memorial, as now extended, is almost boundless. The problems to be investigated relate to the fundamental laws regulating the formation of the stellar system. Questions of such importance should be discussed on a sufficiently large scale, or the results of the discussion will soon be superseded by a repetition of the work. The liberal provision made for the Henry Draper Memorial permits the investigations to be planned on a scale which is likely to avoid such an undesirable duplication of work.


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